LEVERAGING BI-DIRECTIONAL EV CHARGING FOR FLEXIBILITY SERVICES IN THE DISTRIBUTION GRID - THE CASE OF FEVER PROJECT

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ABSTRACT

Distribution System Operators face a challenging environment largely affected by the ever-growing integration of Distributed Energy Resources. Especially, Electric Vehicles have a rapidly growing presence in the distribution grids, being both a challenge, but also an enabler for active network management. This work analyses the operation of charging infrastructures in coordination with the DSO in the context of the FEVER project. The objective of the project is to exploit control of power flow through DC/AC converters towards demand management and voltage compensation. The paper describes the different modules required to coordinate this operation in a flexibility market context. DSO support tools have been developed to forecast possible critical events and prepare a mitigation plan leveraging flexibility. Response to this flexibility demand is covered by Vehicle-to-Grid charging stations, equipped with DC converters, capable of implementing flexibility strategies.

INTRODUCTION

The realisation of the energy transition in the context of electricity grids - with the rapid integration of Distributed Energy Resources (DER) - raises significant operational challenges to the Distribution System Operators (DSOs) and requires a drastic modification in the way electricity grids are designed, planned and operated. The power system is becoming more complex due to its heterogeneity, stochasticity and distributed nature of assets to be controlled.

The high penetration of DERs may provoke significant network operational issues, such as [3]: violation of thermal limits of infrastructure, voltage fluctuation problems, inadequacy of short capacity of network, power quality issues (e.g. harmonic emissions), and disturbed operation of tap changers and of voltage control and protection schemes due to reverse power flows. Complementing network reinforcement with the exploitation of flexibility services can result in higher welfare for all the energy related actors, DSOs included. *System flexibility services* are services provided by market parties and procured by DSOs aiming to maximise the security of supply and the quality of service in the most efficient way. Indicative benefits related to these services include: optimised distribution network capacity investments, reduced technical losses, reduced curtailment of distributed generation and reduced outage times, increased distributed generation hosting capacity [4].

The electrification of transports and most recently the roll-out of Electric Vehicles (EVs) comprise an additional challenge on the electrical grid. The additional load from EVs can stress grid equipment (e.g. transformers), create congestions, and increase power losses in the distribution grid as well as reduce power quality due to voltage fluctuations. Additional investments may be needed for system operators to address such challenges. However, EVs also present a great flexibility potential which can be leveraged by controlling the charging process (smart charging) or even using it as a storage system, able to provide power back to the grid (Vehicle-to-Grid - V2G), deferring or avoiding costly reinforcements and providing a more efficient use of existing assets [5]. Coordinated charging and/or discharging could support the grid in terms of voltage control and congestion management. The injection of active or reactive power in specific nodes could help DSOs to keep the operation of the distribution grid within the regulatory and standard thresholds.

FEVER [1] (*Flexible Energy Production, Demand and Storage-based Virtual Power Plants for Electricity Markets and Resilient DSO Operation*) project implements solutions that leverage the potential of flexibility in generation, consumption, and storage of electricity for optimal management of power grids. A set of tools and services implemented in the project provides the DSOs with the capability to better operate the network. EV-related flexibility is a significant building block of this set.

The rest of the document is structured as follows:

- The next section presents the adopted methodology to analyse the problem domain and design the proposed solution.
- Then, the results of the requirement analysis and design – on the basis of the methodology – are presented. The scope of the presentation is limited to the implemented V2G solution.

- The paper concludes with a summary of the results and a description of the real-life setup in which the solution is deployed for validation.

METHODOLOGY

The development and integration of new functionalities in engineering systems requires a proper analysis and definition methodology that will enable the successful identification and understanding of their technical requirements. Particularly for Smart Grid functionalities that are based on the combination of software and hardware advances, the Use Case (UC) analysis approach is a best practice [6], having been used over the past years in numerous projects. Figure 1 presents the methodology applied for the formulation of FEVER's UCs.

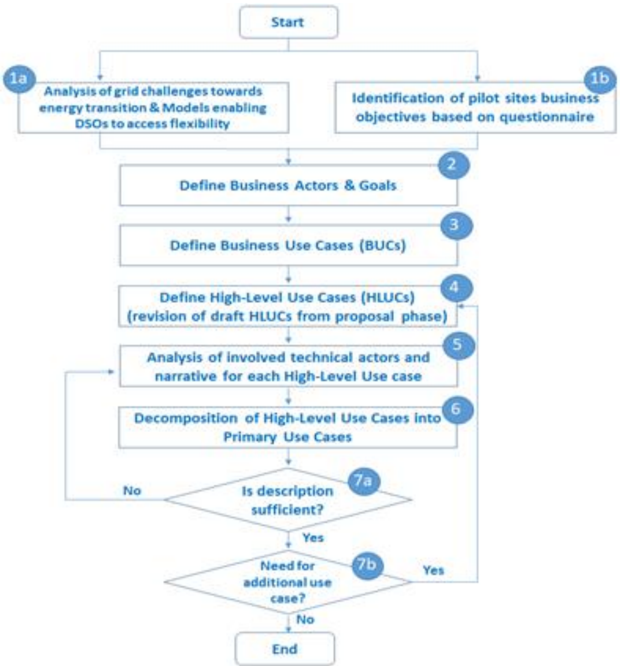

Figure 1 - FEVER UC Analysis Methodology [2]

For documenting different design perspectives covering a diverse set of interoperability aspects the Smart Grid Architecture Model (SGAM) Framework was utilized [6]. SGAM offers support for the design of interoperable Smart Grids solutions with an architectural approach covering different interoperability viewpoints: *business*, *functional*, *component*, *communication* and *information*.

Based on the above methodology, the work performed in FEVER resulted in a set of UCs [2] and in an architectural description that covers the whole value chain of flexibility. In this paper we focus on a subset of these outcomes that is relevant to the orchestration of the operation of V2G infrastructures as a flexibility provider, in response to a flexibility service request issued by the DSO.

RESULTS

Business and Functional Requirements

Maintaining a secure and reliable operation requires in many occasions the reinforcement and extension of distribution networks which can be a significant economic burden for the DSOs. The exploitation of local DER flexibility towards grid operational support is the main objective of the FEVER Business Use Case (BUC) 01: "*Exploit flexibility for preventing network operational issues*", aiming to minimize/delay network reinforcement costs. This can be enabled via preventing network congestion issues at distribution level, leveraging real network operational data, forecasting tools and flexibility-based remedial mechanisms [7].

On the other hand, the grid voltage level undergoes momentary variations, due to sudden changes of consumption and generation. Such cases mostly occur in the presence of long feeders or due to heavy / light loading in the presence of distributed generation. The usage of reactive power for compensating voltage deviations as an improvement to traditional voltage control strategies such as the on-load tap changers (OLTC), is well known in academic literature [8]. Traditionally, the effect of the voltage compensation is diminished the further the flexible asset is from the problematic bus. For limiting overvoltage, lagging reactive power injection is necessary, whereas for increasing the voltage in an under-voltage scenario leading reactive power injection is necessary. FEVER HLUC 02: "*Voltage compensation via reactive power procurement*" aims to identify voltage excursions and exploit reactive energy offered by distributed storage units associated with the problematic grid area, from a local flexibility market.

Flexible assets can be an important source of enhanced network operational efficiency and quality of supply as modelled in FEVER BUC 03: "*Reduce technical losses utilising DER flexibility and power electronics*". For the scope of this work, HLUC 06: "*Leveraging DER flexibility towards enhancing network operational efficiency*", studies the scenario of high RES penetration in the distribution network and how increasing local consumption - at primary or secondary substation level - via exploiting dispatchable DERs can reduce network peaks and enable better exploitation of the existing grid capacity, translated in network technical losses reduction.

Some general considerations of the UCs analysed above are the following:

- **Spatial component of flexibility**: Offered and requested flexibility should be correlated in terms of location since the studied grid issues have local and not systemic characteristics.
- **Availability and quality of data**: The performance of analytical tools highly depend on the data quality, availability and resolution.
- **Market approach**: The exploitation of DER

flexibility by the DSOs can be realised based on bilateral contracts and/or via flexibility markets.

The list of FEVER's BUCs from the DSO's perspective are complemented with BUC 02: "*Advanced network management under critical conditions*", focusing on increasing network security and resilience via self-healing operation (HLUC04), real-time detection of uncontrolled islanding (HLUC03) and islanded microgrid operation (HLUC05) [2]. These UCs are out of scope of the V2G flexibility context explored in this paper.

Architecture

The main architectural components and communication protocols utilised for their interfacing are presented in the SGAM Communication layer of Figure 2. The model considers the protocols utilized in the actual pilot setup.

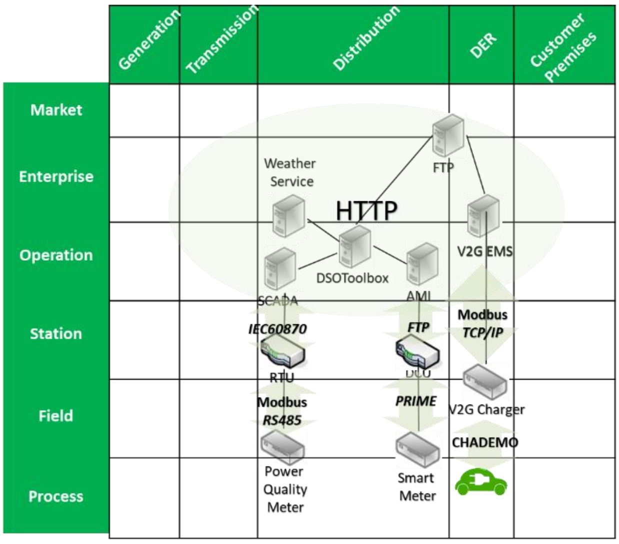

Figure 2 - SGAM Communication Layer

The main components of the design are the following:

- DSO Toolbox: a suite of grid-oriented tools complementing the DSO's legacy IT systems whilst enabling more advanced observability and management of the distribution grid. It contains among others the Critical Event Prevention Application (CEPA) and the Voltage Compensation Application (VCA), and exposes DSO's flexibility needs to the market.
- DS SCADA: DSO's system enabling access to monitoring data at substation or feeder level.
- Meter Data Management System (MDMS): DSO's system enabling access to Smart Meter (SM) data on a regular basis.
- Flexibility Trading Platform (FTP): The system responsible for the trading of flexibility among different stakeholders.
- V2G Energy Management System (EMS): Aggregates several charging stations and controls EVs' charging and discharging, offering their flexibility to the market.
- V2G Charger: Bi-directional charging station (depicted as an asset controller in Figure 2).

A dominant role in communications among the above components is assumed by HTTP protocol, whilst for the V2G Charger to V2G EMS communication MODBUS TCP/IP protocol is used. For the DSO's supporting infrastructure: SMs communicate via PRIME with Data Concentrator Units (DCUs) - located in secondary substations - which communicate with MDMS via FTP protocol (i.e. DC-STG); Power Quality Meters (PQMs) provide data via MODBUS RS-485 protocol to a Remote Terminal Unit (RTU), which communicates via IEC-60870-5-104 to the SCADA.

The main functionalities of the solution are exposed in the SGAM function layer (Figure 3), providing a coarse generic view of the main functions of the HLUCs.

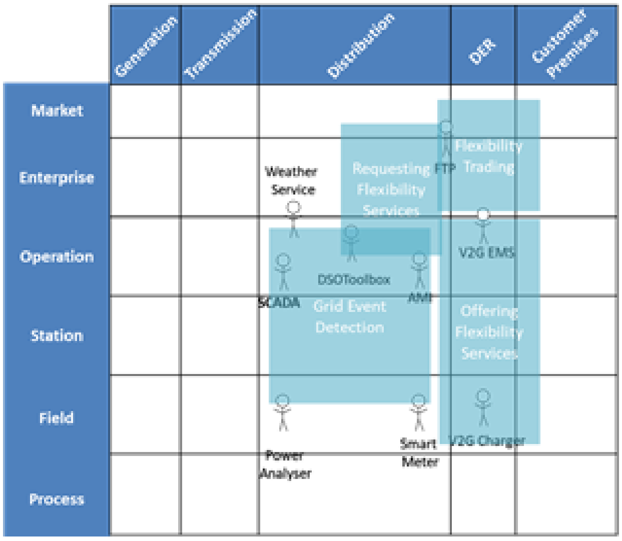

Figure 3 - SGAM Function Layer

The main functions concern:

1) Grid Event Detection: Forecasting possible voltage variations and/or load peaks based on information gathered from the grid monitoring infrastructure.
2) Requesting Flexibility Services: Estimation of flexibility demand (active and/or reactive energy injection/absorption) at specific grid nodes and time periods.
3) Offering Flexibility Services: Calculation of flexibility of EV assets and offering it for grid services via the market.
4) Flexibility Trading: Trading of flexibility and activation at the specified time.

Main Building blocks

Grid Observability

Ongoing transformation of Low Voltage (LV) distribution grids imposes the need for better observability at the level of the DSO's control centre. Even for grids with extended

SM deployment, a more granular and frequent data feed is needed. PQMs can provide near real-time data enhancing observability of LV grids. In the case of FEVER, PQMs were installed in strategic locations for monitoring problematic areas, whereas an update frequency of 4 sec (at the level of SCADA) was selected.

Critical Event Prevention Application

CEPA is a decision support tool designed to forecast possible critical events in the LV grid and calculate a flexibility demand to mitigate them. The basic procedure encompasses three steps: 1) Energy forecasting of demand and generation at prosumer/substation level; 2) Violation identification utilizing a power flow simulation and detecting possible critical events of current (i.e. congestions) according to operation thresholds; and 3) Proposal of mitigation actions, specifying a flexibility demand vector for specific times and grid points in order to mitigate the forecasted events. As a result of the forecast, the current at every segment of the grid can be assessed after running a power flow simulation. Figure 4 shows an example of the day-ahead (24h) current profiles (normalised to the maximum segment rate) in fifteen representative segments of the FEVER pilot grid.

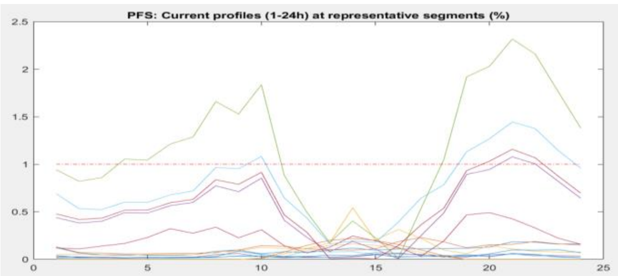

Figure 4 - Example of 24h current profiles in representative segments of a grid in the FEVER pilot

Evaluation of operational thresholds results in possible critical events, as exemplified in Figure 5. Two forecasted events for segment '155722' occur between 9 and 10h, and a second one between 18 and 23h. As a result of these possible events, a plan is calculated with required flexibility to avoid them. The lower picture in Figure 5 indicates two scenarios: yellow bars represent the minimal power required to solve the contingency and the blue ones an optimal based on expected availability of flexibility.

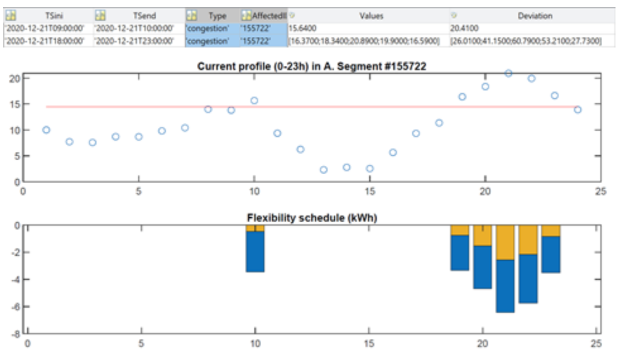

Figure 5 - Critical event and flexibility demand

Voltage Compensation Application

Usually DSOs make use of OLTC to attenuate voltage drops, shifting the voltage levels and solving permanent issues. However, for feeders whose voltage levels greatly vary along the day, this may not be a feasible solution. Also, secondary substations often do not have advanced communication or controllability nor OLTC. The VCA detects such problems and leverages the flexibility of EVs for resolving them. Figure 6 depicts the voltage level for every bus in the network during a whole day for a MV-LV distribution grid in Spain. For the most part and depending on the location, the grid is resilient and is kept within the regulatory limits. However, few parts of the network - especially in rural areas where LV cables are deployed for long distances- are more susceptible to voltage changes. This is more evident during the night, when demand is usually at its peak and the solar panels stop generating, which can result in voltage drops as seen in the figure.

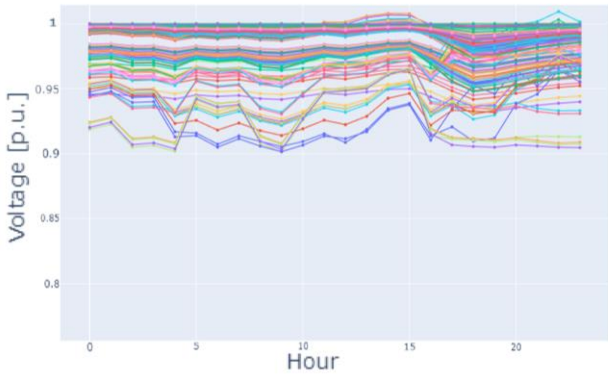

Figure 6 - Voltage per bus prior to flexibility activation

Figure 7 shows the results of EV flexibility activation. It was necessary to inject a maximum of 13 kVAr of reactive power during peak hours in the most critical bus, while minor injections of 2 kVAr required in other buses. In some cases a small amount of active power is also needed. It can be seen that flexibility activation is able to compensate voltage drops and maintain it within the regulatory limits. These results were obtained with synthetic data for load and generation, but exemplify the potentiality of the application.

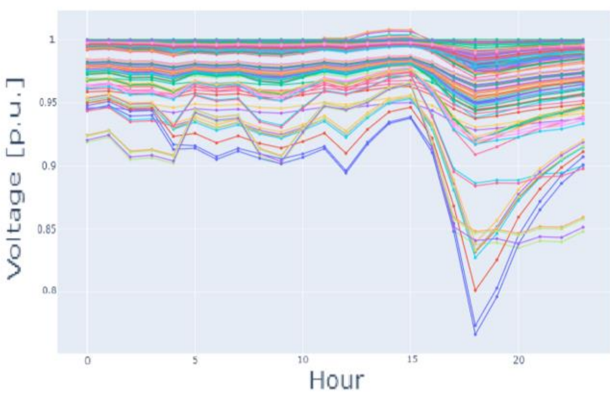

Figure 7 - Voltage per bus after flexibility activation

Integration Platform

The Integration Platform is a software solution that enables secure communication of the various tools (e.g. CEPA, VCA) with legacy IT systems of a DSO, facilitating access to field data, whilst it interfaces with the market solution for requesting/managing flexibility. It also provides a graphical user interface for monitoring and controlling the various operations.

V2G Energy Management System

The last building block is the one in charge of extracting the energy flexibility from the particular batteries of EVs and activating it at the specified time and location. The V2G EMS aggregates and controls several bi-directional charging stations that allow the charging and discharging of the EVs and the extraction of both active and reactive power. This power is offered to the flexibility market or to the FTP in exchange for economic compensation.

The operation of the flexibility trading is as follows: the V2G EMS calculates the potential flexibility of the aggregated set of V2G chargers, and makes a time and power flexibility offer to the flexibility market. If the FTP finds a match between flexibility offers and the grid needs (considering as well the location of such flexible assets) it sends back to the V2G EMS a flexibility request in a demand schedule form, specifying the time and amount of power in which the V2G chargers should charge and discharge the plugged EVs. If the request is technically feasible, the EMS accepts it and operates the chargers to supply the power when agreed.

Additionally, the V2G EMS integrates an economic optimization by implementing an approach to minimise battery degradation, as well as optimising the charging/discharging operation. The strategy is based on a model that considers both calendar and cycling ageing [9].

CONCLUSIONS AND FUTURE WORK

The electrification of transportation (particularly the ever-increasing penetration of EVs) as well as the ambitious targets for further integration of distributed renewables and storage comprise not only a challenge but also an opportunity for the electricity distribution grid. Tools capable of providing observability and the possibility to manage power can contribute to the integration of EV's while avoiding/deferring traditional investments in the DSO infrastructure.

The tools presented in this paper are integrated within a complete suite (a *toolbox)* that can enhance Distribution Management Systems by exploiting both smart metering and SCADA data, as well as the flexibility provided by aggregated prosumers. This suite will be demonstrated in one of the FEVER's pilots i.e. in the grid operated by Estabanell Distribució. The setup of the pilot contains several flexible assets (e.g. V2G chargers controlling the EV batteries, a pair of power converters connected to stationary batteries). Moreover, three-phase inverters can provide other services such as power quality enhancement and island detection and management. The V2G chargers, commissioned for the FEVER project, are single phase bidirectional chargers that have an integrated 3.6 kVA power electronic converter, which allows working independently of battery voltage level between 230 and 500 V each one. The AC rated voltage is 230V and the rated current is 16A.

ACKNOWLEDGMENTS

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